

# Lunar Relay Coverage Analysis for RF and Optical Links

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## Outline

- Introduction
- Notional Lunar Relay Architecture Options for RF Links
  - Three Relay Orbiters – Two at Polar Frozen Elliptical Orbits, and One at Equatorial Circular Orbit
  - One Relay Orbiter in a 74-Day Lissajous Orbit at the Earth-Moon Lagrange Point L2
  - One Relay Orbiter in a 14-Day Lunar Distance Retrograde Orbit (Not shown)
- Notional Lunar Relay Architecture for Optical Links
- Concluding Remarks

## Introduction (1)

- Planned Lunar missions in the next ten years

Mission	Launch Yr	Agency	# of Vehicles	Mission Type
Chandrayaan-2	2018	ISRO	3	Orbiter/lander/rover
Chang'e 4	2018	CNSA	2	Lander/rover
Chang'e 5	2017	CNSA	2	Orbiter/rover for sample return
Chang'e 6	2020	CNSA	2	Orbiter/rover for sample return
KPLO	2018	KARI	1	Orbiter
Korean Lunar Mission	2021	KARI	3	Orbiter/lander/rover
Luna 25	2024	RFSA	1	Lander
Luna 27	2020	RFSA	1	Rover
Luna 26	2020	RFSA	1	Orbiter
SLIM	2019	JAXA	1	Lander
SELENE-2*	2022	JAXA	3	Orbiter/lander/rover
Resource Prospector*	2020	NASA	2	Lander/rover
EM-1**	2018	NASA	1	Orbiter
EM-2**	2020	NASA	1	Orbiter
Lunar Flashlight	2018	NASA	1	CubeSat Orbiter
Lunar IceCube	2018	NASA	1	CubeSat Orbiter
Lunar H-Mapper	2018	NASA	1	CubeSat Orbiter
ArgoMoon	2018	ASI	1	CubeSat Orbiter
SLSSLIM	2018	JAXA	1	CubeSat Lander
EQULEUS	2018	JAXA	1	CubeSat Orbiter

$$\Delta A = \pi r^2$$

## Introduction (2)

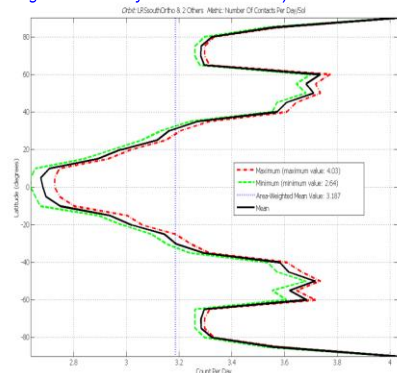
- The moon is unique in the following way
  - Moon is rotation at the same rate as its revolution of 27.3 days, resulting in permanently shielded far-side
  - Earth's ground stations (DSN's 3 sites) can always cover the near-side
  - Orbiters at Moon are affected by Moon, Earth, and Sun
- Criteria on choosing lunar relay architecture
  - Orbit(s) should be stable to minimize  $\Delta V$
  - Range should be small to minimize space loss
  - High average contact duration across all latitudes
  - High percentage of contact time across all latitudes
  - Small maximum gap time across all latitude

# RF Option 1: 2 Polar Frozen, 1 Equatorial Circular (1)

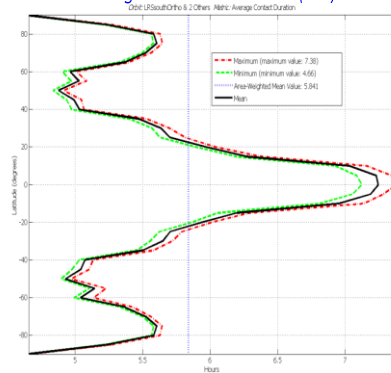
Lunar Satellite Orbits	semi-major Axis (km)	Eccentricity	Inclination (deg)	Ascending Node (deg)	Argument of Perilune (deg)	Mean Anomaly (deg)
12-Hr Circular Equatorial	6142.4	0	0	0	315	0
12-Hr Elliptical North	6142.4	0.59999	57.7	270	270	0
12-Hr Elliptical South	6142.4	0.59999	57.7	0	90	0

## Coverage Performance of Three Relay Orbiters

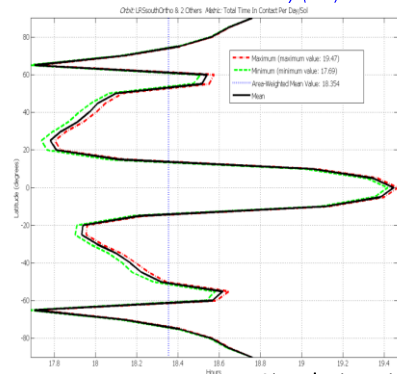
Average Number of Contacts Per Day



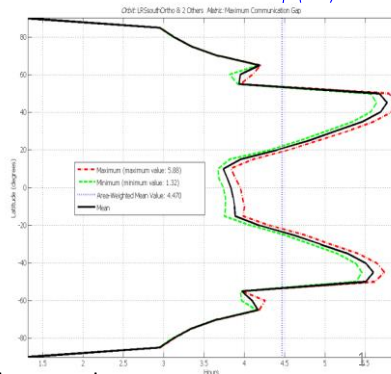
Average Contact Duration (hrs)



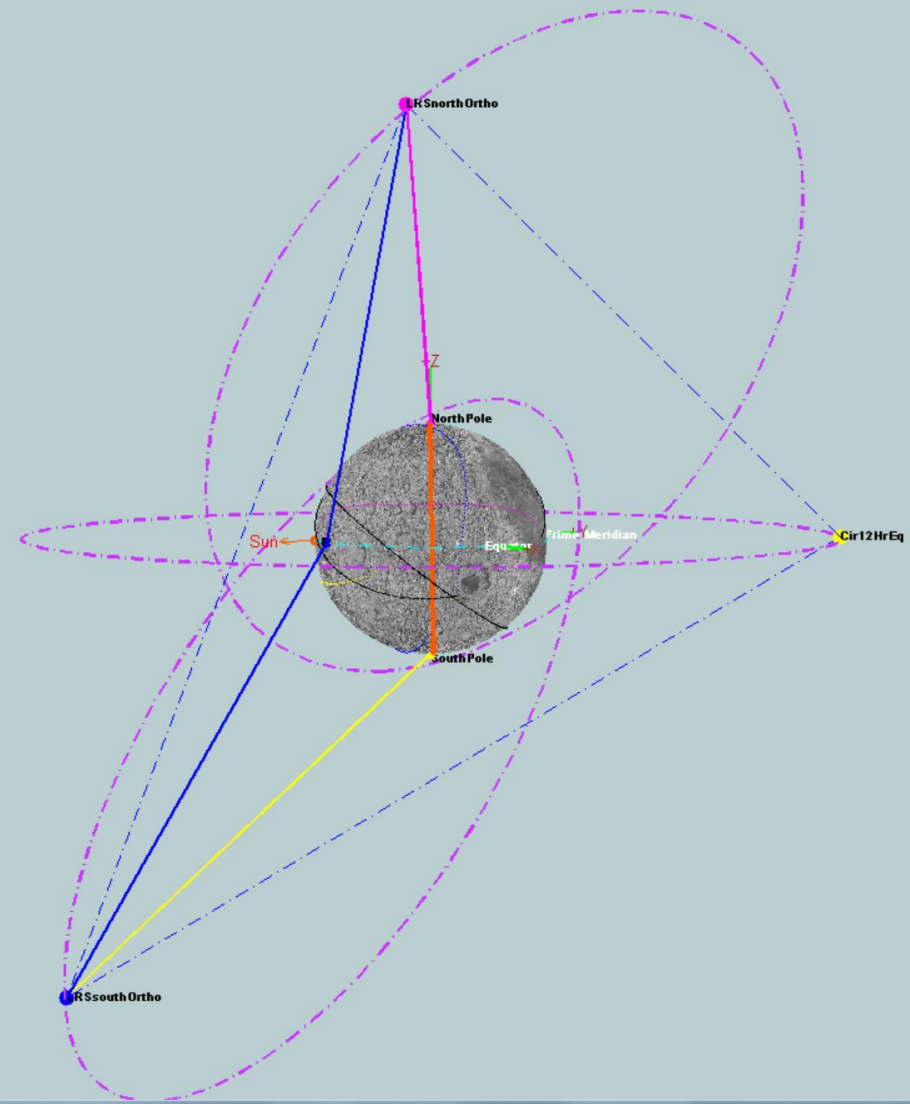
Total Contact Time Per Day (hrs)



Max Communication Gap (hrs)



Simulation time = 2 lunar cycles



## RF Option 1: 2 Polar Frozen, 1 Equatorial Circular (2)

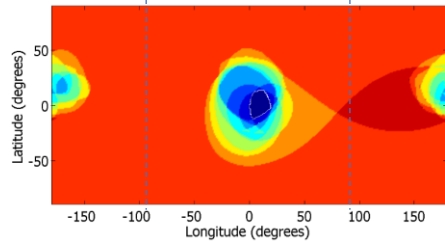
- Pros
  - Can be built up incrementally – S. Pole, Equator, N. Pole
  - Offer good and relatively even coverage at different latitude
    - Long contact duration (5 – 7 hours)
    - Large total contact time per day (17.6 – 19.4 days)
    - Short gap time (1.4 – 5.8 hours)
- Cons
  - Requires launching three satellites into orbit

# RF Option 2: 1 Relay Orbiter in a 74-Day Lissajous Orbit (1)

## Lunar 74-Day Lissajous Orbit (far side coverage)

### Average Number of Contacts Per Day

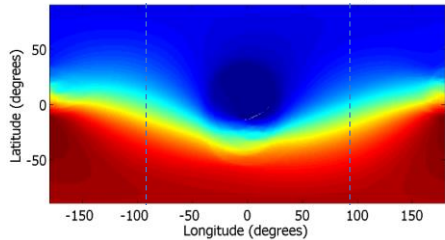
Orbit: LunarL2DSH Metric: Number Of Contacts Per Day/Sol Units: Count Per Da



Simulation Interval: 2019 DEC 25 19:45:00 to 2020 MAR 10 13:30:00  
Duration: 17:45:00

### Total Contact Time Per Day (hrs)

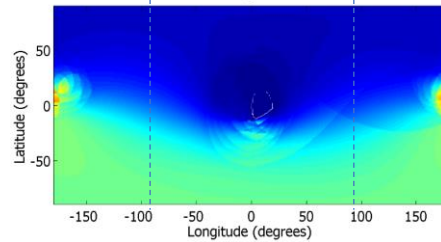
Orbit: LunarL2DSH Metric: Total Time In Contact Per Day/Sol Units: Hours



Simulation Interval: 2019 DEC 25 19:45:00 to 2020 MAR 10 13:30:00  
Duration: 17:45:00

### Average Contact Duration (hrs)

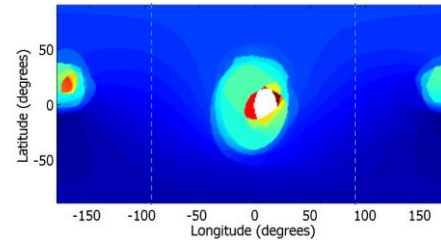
Orbit: LunarL2DSH Metric: Average Contact Duration Units: Hours



Simulation Interval: 2019 DEC 25 19:45:00 to 2020 MAR 10 13:30:00  
Duration: 17:45:00

### Max Communication Gap (hrs)

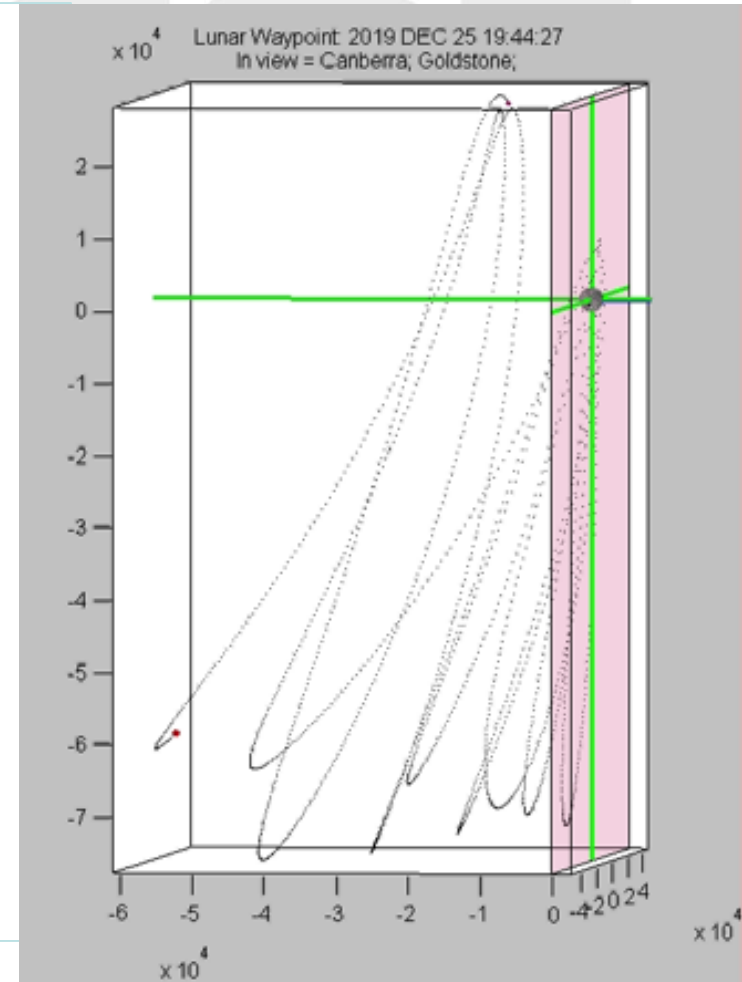
Orbit: LunarL2DSH Metric: Maximum Communication Gap Units: Hours



Simulation Interval: 2019 DEC 25 19:45:00 to 2020 MAR 10 13:30:00  
Duration: 17:45:00

Simulation time = 76 days

3



## RF Option 2: 1 Relay Orbiter in a 74-Day Lissajhous Orbit (2)

- Highlights of coverage performance
  - Covers most of lunar far-side, except the far-side equator
  - Favors the far side S. Pole
  - 0.8 – 1.2 contacts per 10 days
  - Average contact 20 to 170 hours
  - Range can be as long as 90000 km
  - Communication gaps can be 90 hours or more
  - S. Pole has no or low visibility with Earth, and has to rely on relay orbiter
  - An additional ground station in S. Hemisphere (e.g. Heetebeesthoek, S. Africa) helps to eliminate the daily short gaps



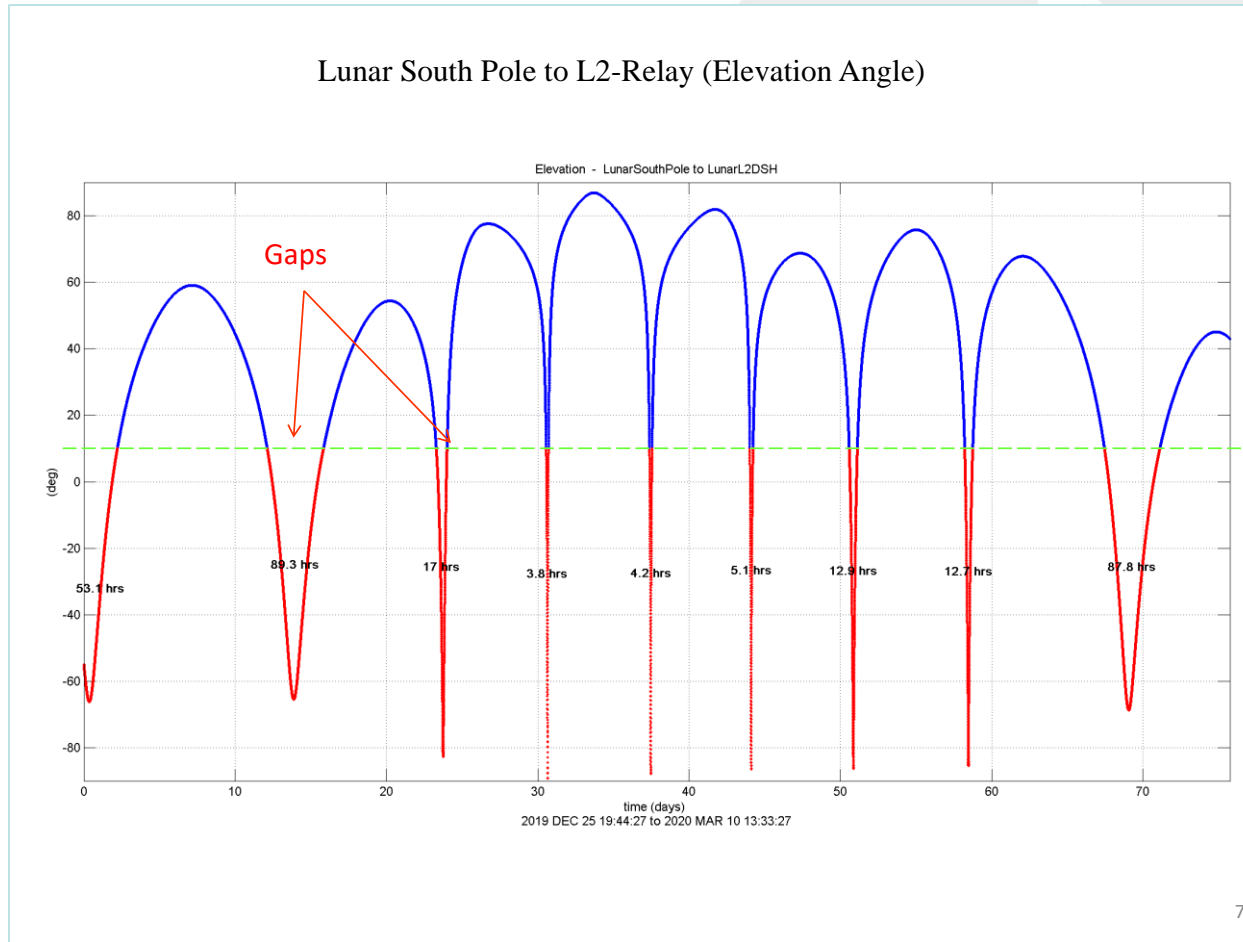
## Notional Lunar Relay Architecture for Optical Links (1)

- We consider a lunar relay architecture that consists of
  - A lunar relay orbiter in a 74-day Lissajous orbit at Earth-Moon L2
  - 3 Earth-orbiting relay orbiters at 3 TDRSS GEO locations G, K, and H
  - 3 optical ground telescopes at White Sands, Guam, and Tenerife
- For optical links, we consider the additional coverage constraints
  - Sun-"Earth"-Probe (SEP)  $< 10^\circ$ , Sun-Probe-"Earth" (SPE)  $< 3^\circ$
- Consider coverage of 4 optical links
  - A. Lunar S. Pole to L2-Relay
  - B. L2-Relay to TDRSS
  - C. Lunar near-side (longitude/latitude =  $0^\circ/0^\circ$ ) to TDRSS
  - D. TDRSS to optical ground telescopes



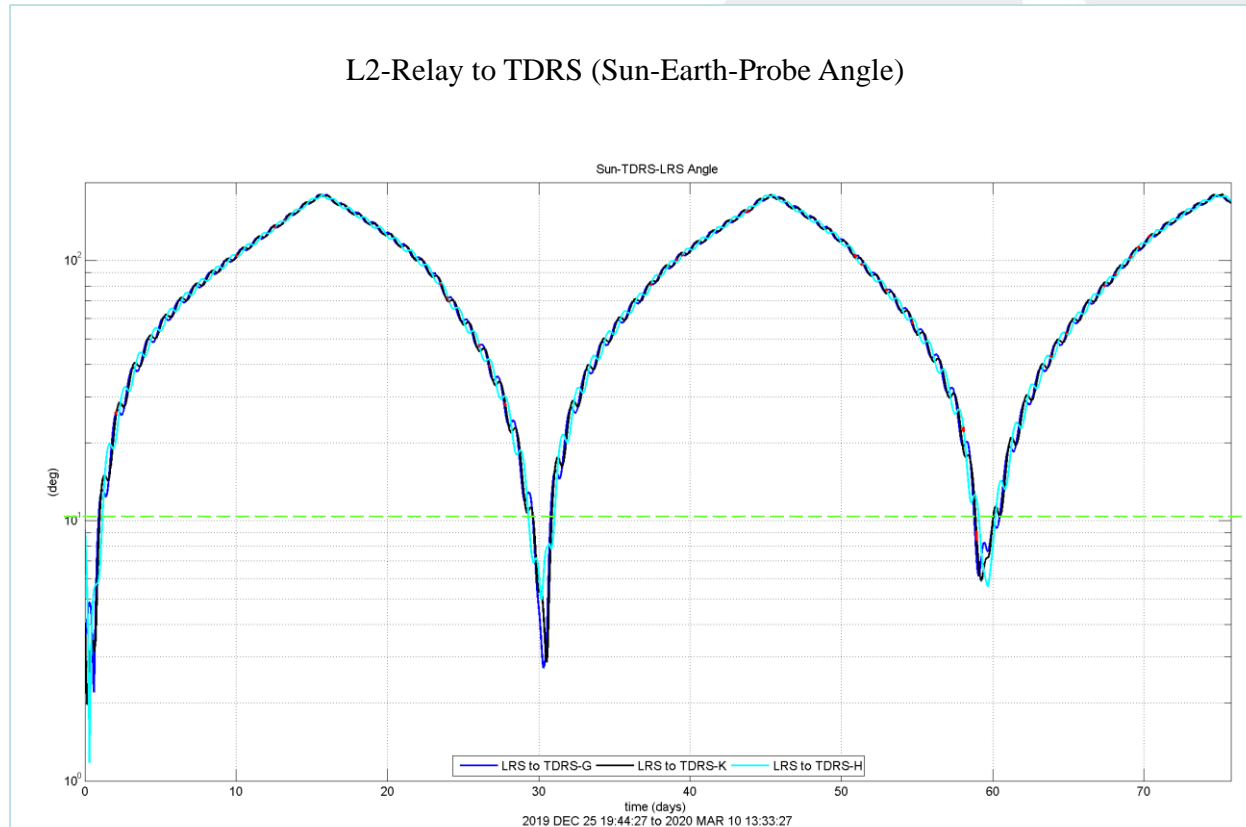
## Notional Lunar Relay Architecture for Optical Links (3)

- A. Lunar S. Pole to L2-Relay Link (74-day period)
  - 9 gaps ranging from 3.8 to 89.3 hours



## Notional Lunar Relay Architecture for Optical Links (4)

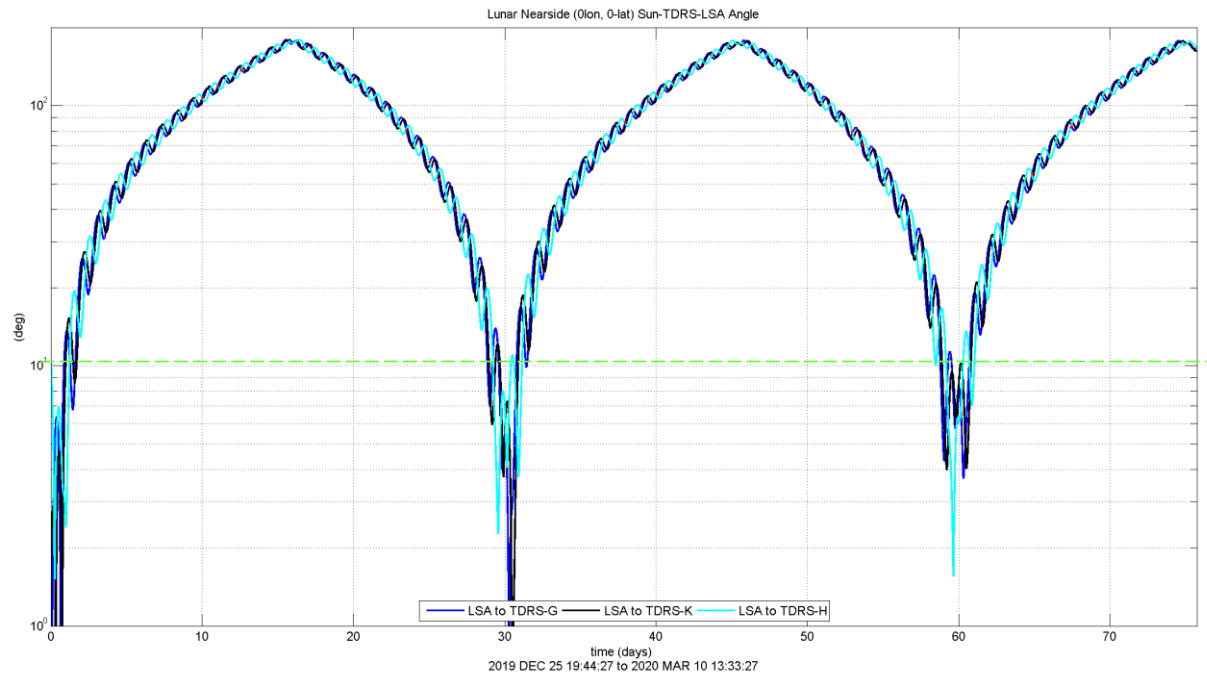
- B. L2-Relay to TDRSS Link (Space-to-Space Link)
  - 1.5-day gap every 27.3 days



## Notional Lunar Relay Architecture for Optical Links (5)

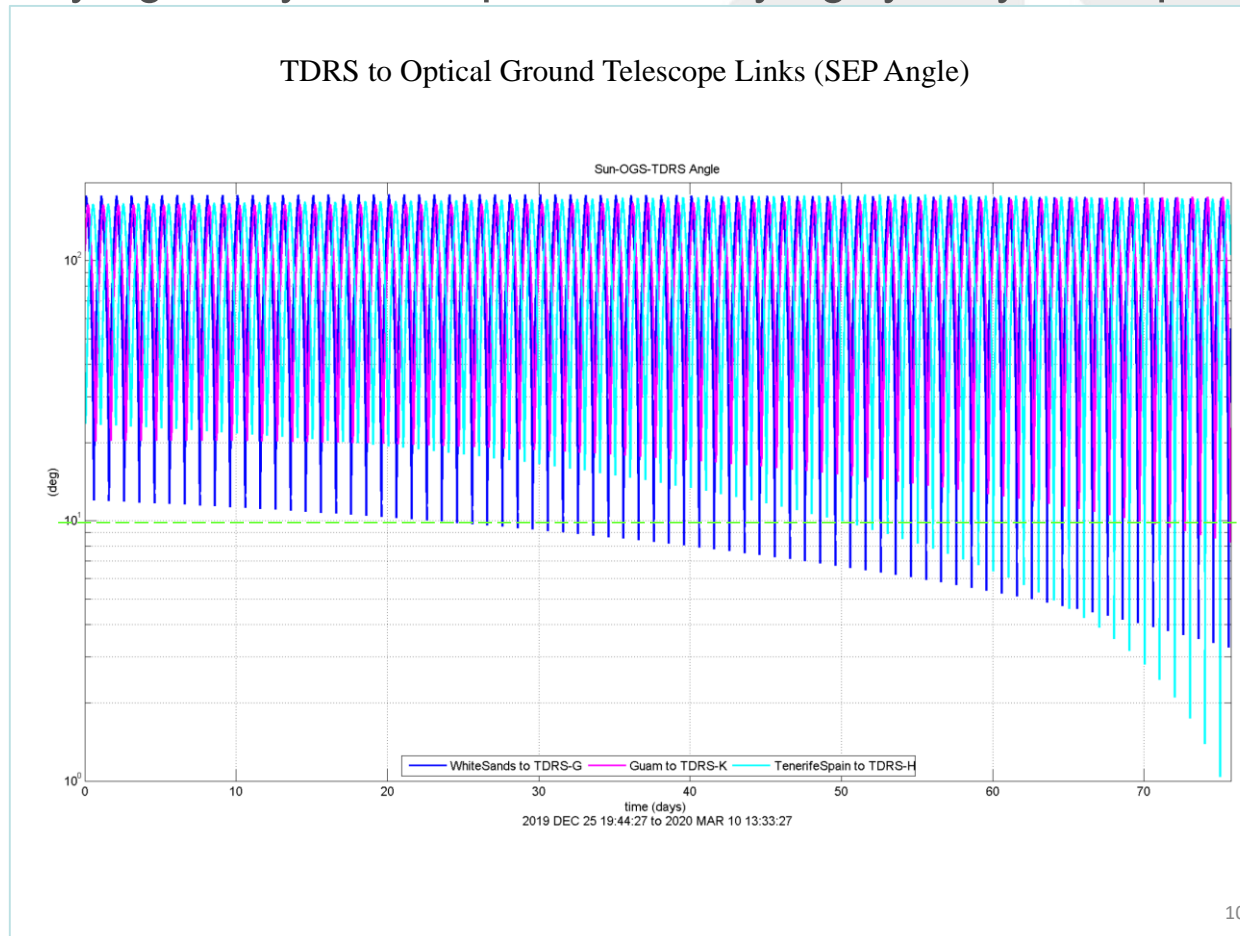
- C. Lunar near-side ( $0^\circ/0^\circ$ ) to TDRSS Link (Space-to-Space Link)
  - 1.5-day gap every 27.3 days

Lunar Nearside (0-latitude, 0-longitude) to TDRS (SEP Angle)



## Notional Lunar Relay Architecture for Optical Links (6)

- D. TDRSS to Ground Telescope Link (Space-to-Ground Link)
  - “Fast-varying” daily SEP dip, “slow-varying” yearly SEP profile



## Concluding Remarks

- This paper describes our effort of searching different lunar relay architectures and assessing their coverage performance and other pros and cons for RF and optical links
- RF link coverage is affected by elevation angle, and to a small extend by SEP and SPE angles
- Operational challenge: long optical link outage due to SEP/SPE angles
  - Earth-Mars system – 1.9 years, SEP outage (long synodic period) for 2.5 months every 2 years
  - Earth-Jupiter system – 11.9 years, SPE outage (Earth's rotation) of 33 days every 6 months



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